Fig 1 Left column: absolute values for the first 10 WH signals (WH0 – WH9, top to bottom) in both time and frequency domains. Right column: real values for the same 10 WH signals in the time domain.
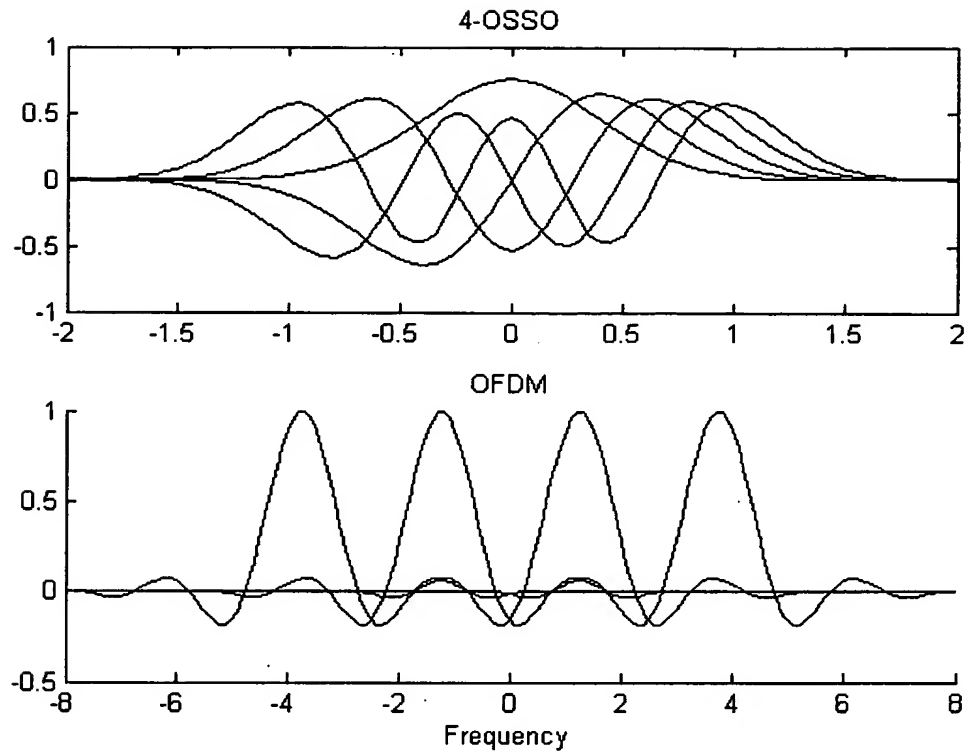
Fig 2 Top: the envelope of an OSSO symbol composed of four WH signals – hence 4-OSSO represented in both the time and frequency domains. Bottom: an Orthogonal Frequency Division Multiplexing (OFDM) symbol in the frequency domain. In the case of OSSO, signal orthogonality is a due to zero cross-correlation of the WH signals. In the case of OFDM, signal orthogonality is due to the displacement of the frequency content of each signal in the frequency domain.

Real WH0–9

$\sqrt{2\pi}\times t \text{ or } \sqrt{2\pi}\times f$

Real 4–OSSO Envelope

$\sqrt{2\pi}\times t \text{ or } \sqrt{2\pi}\times f$

Real 4–OSSO Envelope

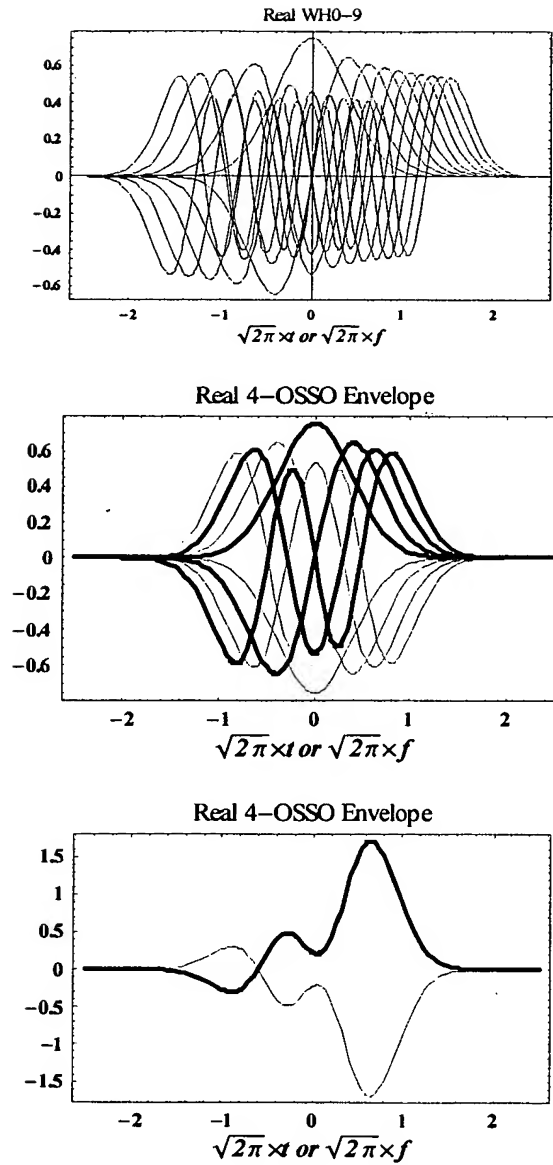$\sqrt{2\pi}\times t \text{ or } \sqrt{2\pi}\times f$

Fig 3 Top: Representation of the envelope of a 10-OSSO symbol showing 10 WH signals (WH0 – WH9) before summation, and in both the time and frequency domains and in either I or Q; Middle: Representation of the envelope of a 4-OSSO symbol showing 4 WH signals (WH0 – WH3) before summation, and in both the time and frequency domains and in either I or Q. Bottom: Representation of the envelope of a 4-OSSO symbol after summation in both the time and frequency domains and in either I or Q.
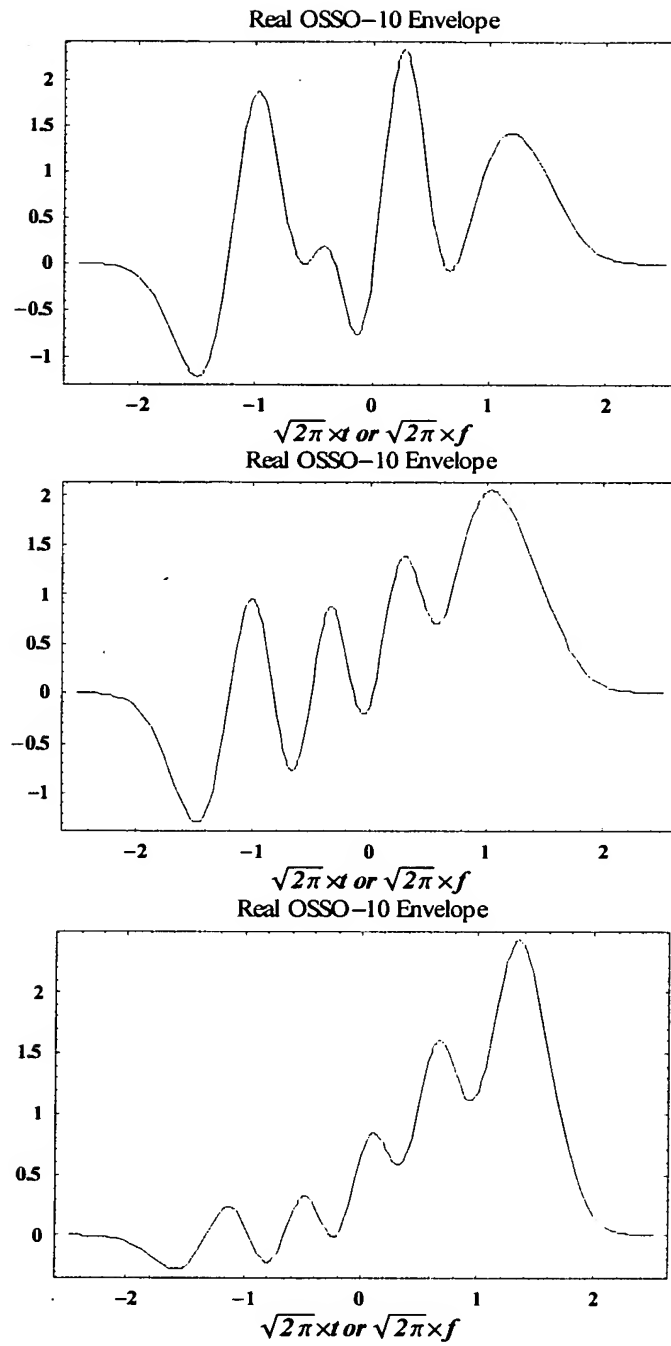
Real OSSO–10 Envelope

$\sqrt{2\pi} \times t \ or \ \sqrt{2\pi} \times f$

Real OSSO–10 Envelope

$\sqrt{2\pi} \times t \ or \ \sqrt{2\pi} \times f$

Real OSSO–10 Envelope

$\sqrt{2\pi} \times t \ or \ \sqrt{2\pi} \times f$

Fig 4 Representative examples of 10-OSSO symbols in either the time or frequency domain after summation and in either I or Q.

0000   0001   0011   0010

1000 ● 1001 ● 1011 ● 1010 ●

1100 ● 1101 ● 1111 ● 1110 ●

0100 ● 0101 ● 0111 ● 0110 ●

Real OSSO−10 Envelope
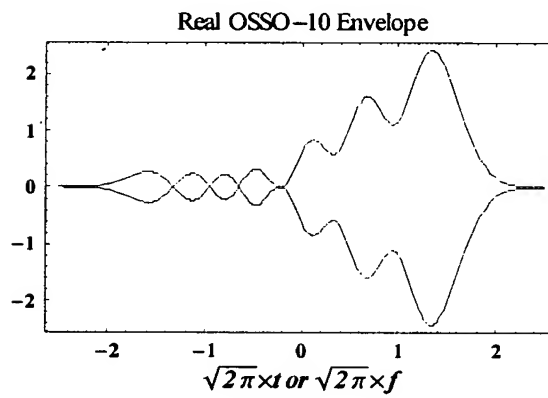
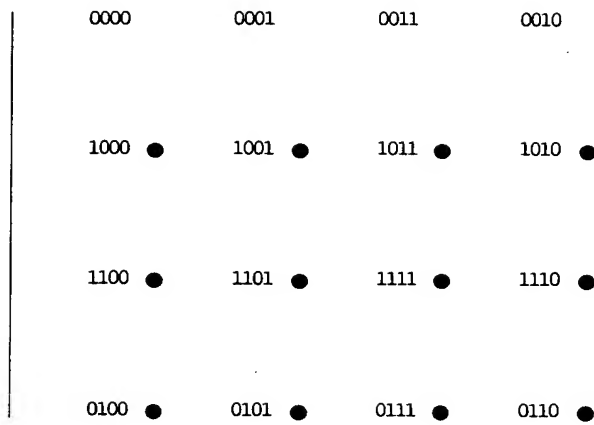$$\sqrt{2\pi}\times t \; or \; \sqrt{2\pi}\times f$$

Fig 5 Top: 16-QAM constellation. Bottom: representative 10-OSSO in either the time or frequency domains and in either I or Q. Each of the WH signals in an OSSO symbol is independently modulated according to a QAM scheme in I and Q.

Real OSSO−10 Envelope

$\sqrt{2\pi}\times t \ or \ \sqrt{2\pi}\times f$

Real OSSO−10 Envelope

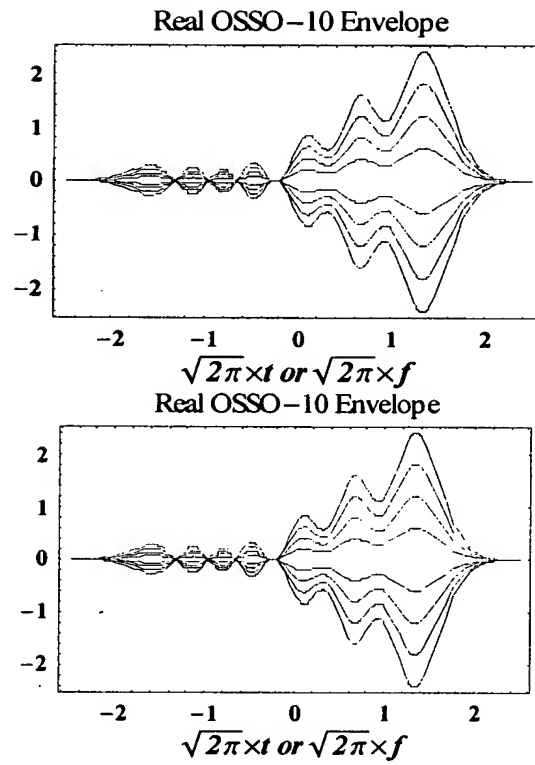$\sqrt{2\pi}\times t \ or \ \sqrt{2\pi}\times f$

Fig 6 Representative 10-OSSO symbols in the time or frequency domains and in I or Q showing possible amplitude levels and with all WH signals equally amplitude modulated.
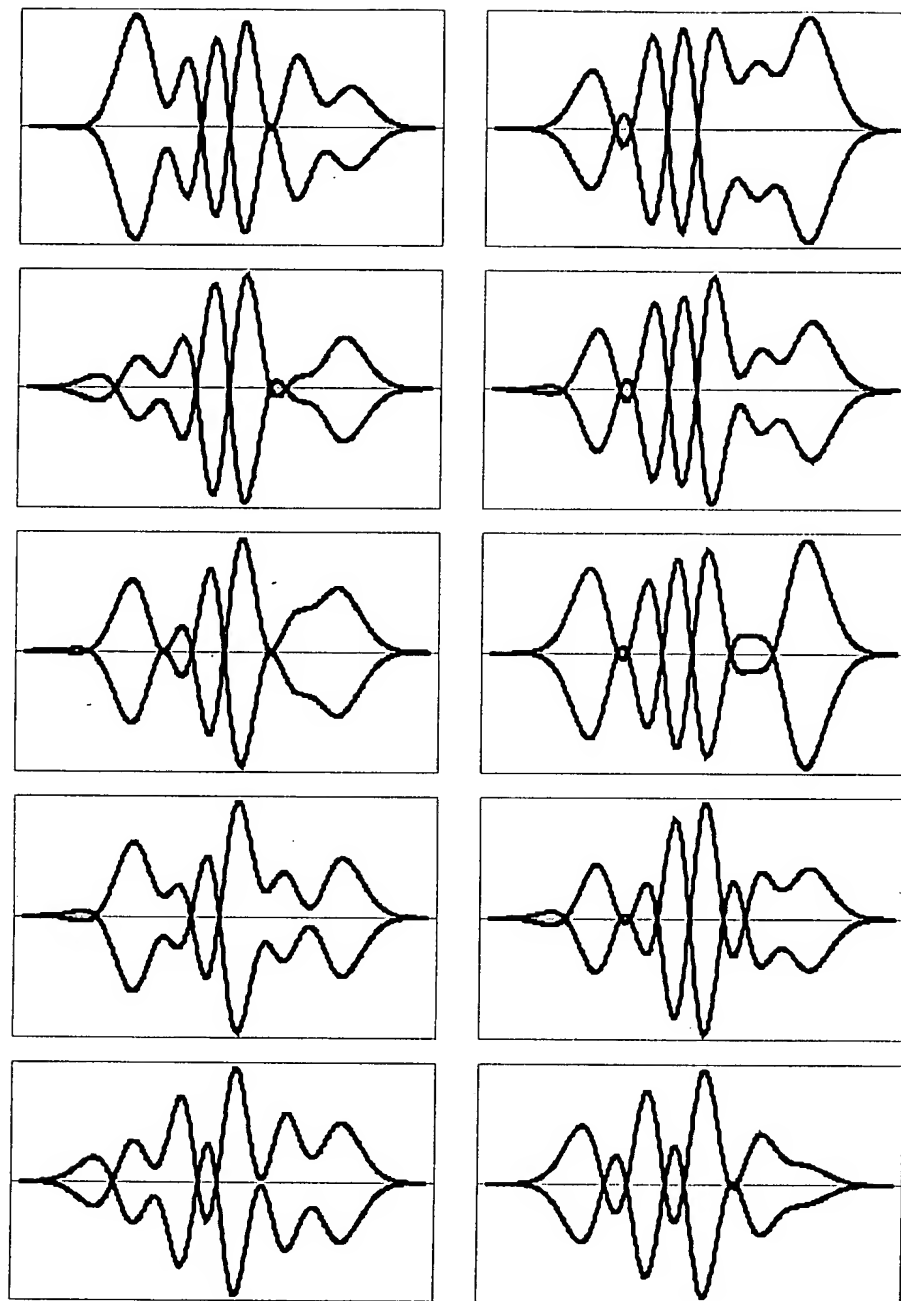
Fig 7 Representative 10-OSSO symbols with all WH signals independently amplitude modulated and in either I or Q.

CROSS-CORRELATIONS: TIME DOMAIN

PRESENT

WH Signals: 0- 9

Crosscorrelation Absolute WH- 0

A

ABSENT

WH Signals: 1- 9

Crosscorrelation Absolute WH- 0

B

WH Signals: 0- 9

Crosscorrelation Absolute WH- 9

C

WH Signals: 0- 8
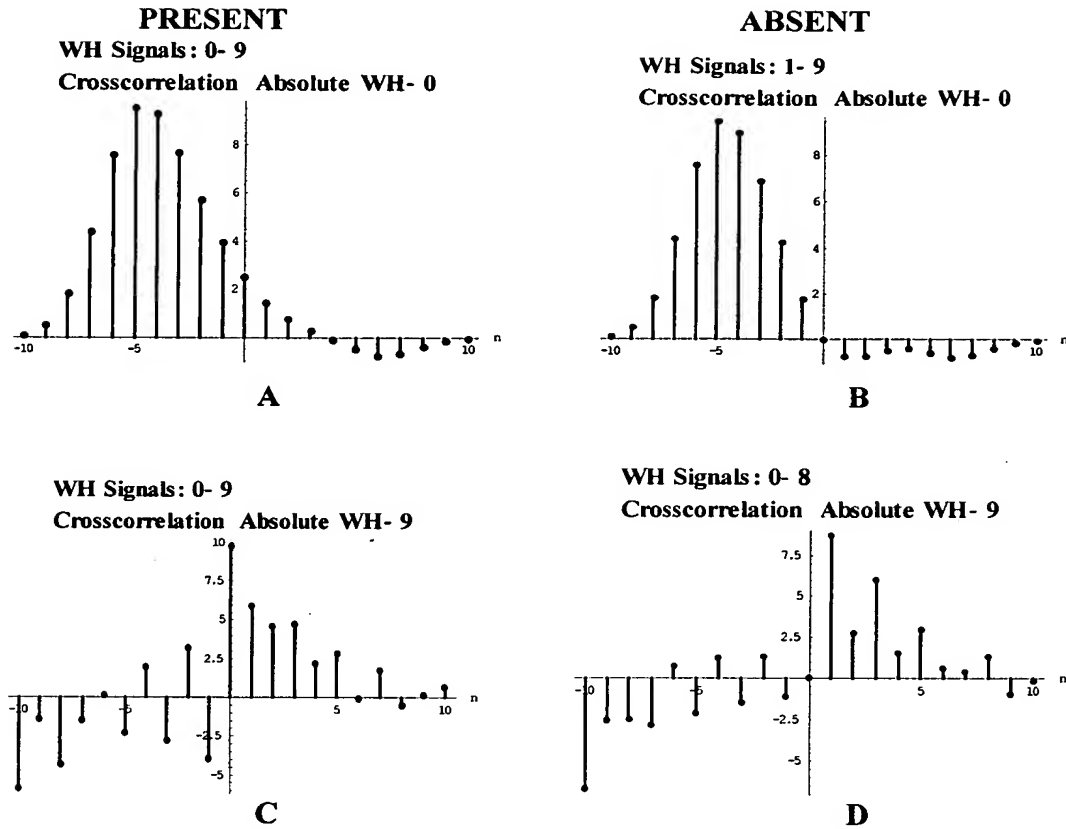
Crosscorrelation Absolute WH- 9

D

Fig 8A Examples of cross-correlations of signal templates with OSSO symbols in the time domain. Cross-correlations of A: The WH0 signal template with a 10-OSSO symbol in which WH0 is present, and B: with a 9-OSSO symbol in which the WH0 signal is absent. In A, there is a finite amplitude at the zeroth time position; in B the amplitude is zero. Cross-correlations of C: The WH9 signal template with a 10-OSSO symbol in which WH9 is present, and D: with a 9-OSSO symbol in which the WH9 signal is absent. In C, there is a finite amplitude at the zeroth time position; in D the amplitude is zero.

CROSS-CORRELATIONS: FREQUENCY DOMAIN

PRESENT

Frequency Domain
WH Signals: 0- 9
Crosscorrelation Absolute WH- 0

A

ABSENT

Frequency Domain
WH Signals: 1- 9
Crosscorrelation Absolute WH- 0

B

Frequency Domain
WH Signals: 0- 9
Crosscorrelation Absolute WH- 9

C

Frequency Domain
WH Signals: 0- 8
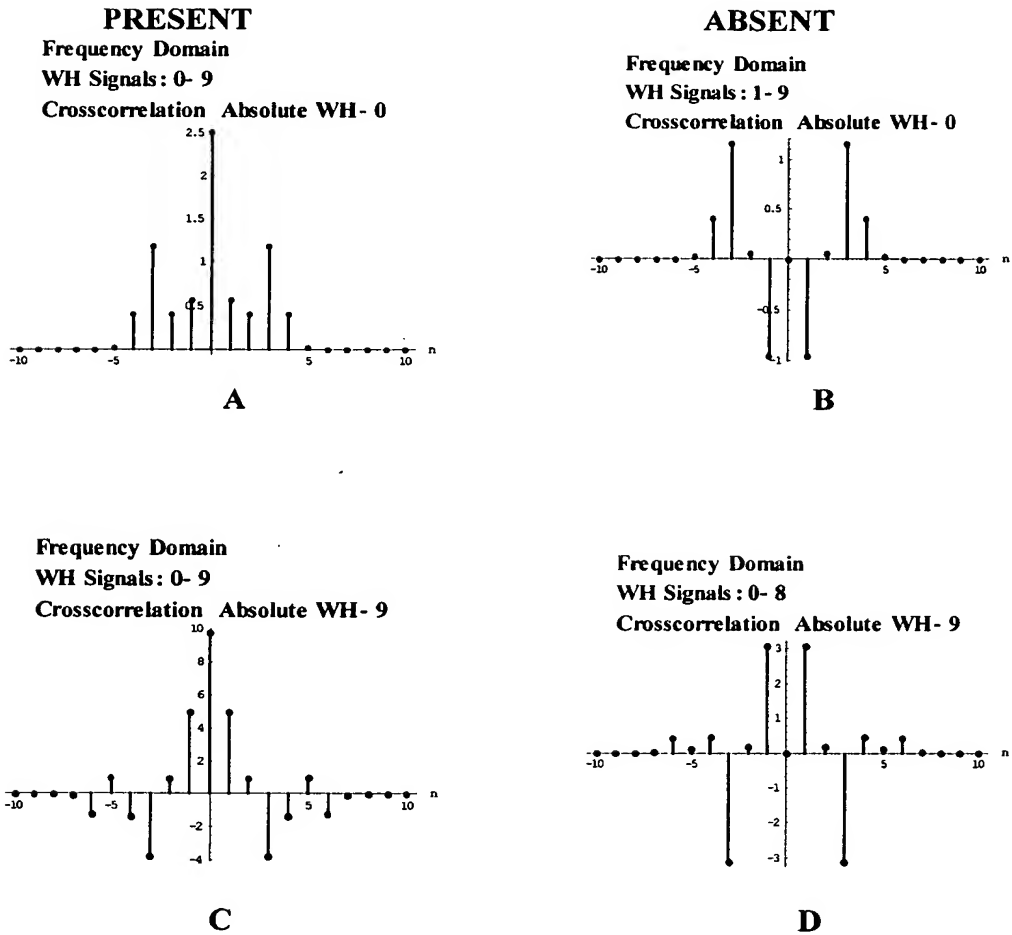Crosscorrelation Absolute WH- 9

D

Fig 8B Examples of cross-correlations of signal templates with OSSO symbols in the frequency domain. Cross-correlations of A: The WH0 signal template with a 10-OSSO symbol in which WH0 is present, and B: with a 9-OSSO symbol in which the WH0 signal is absent. In A, there is a finite amplitude at the zeroth time position; in B the amplitude is zero. Cross-correlations of C: The WH9 signal template with a 10-OSSO symbol in which WH9 is present, and D: with a 9-OSSO symbol in which the WH9 signal is absent. In C, there is a finite amplitude at the zeroth time position; in D the amplitude is zero.
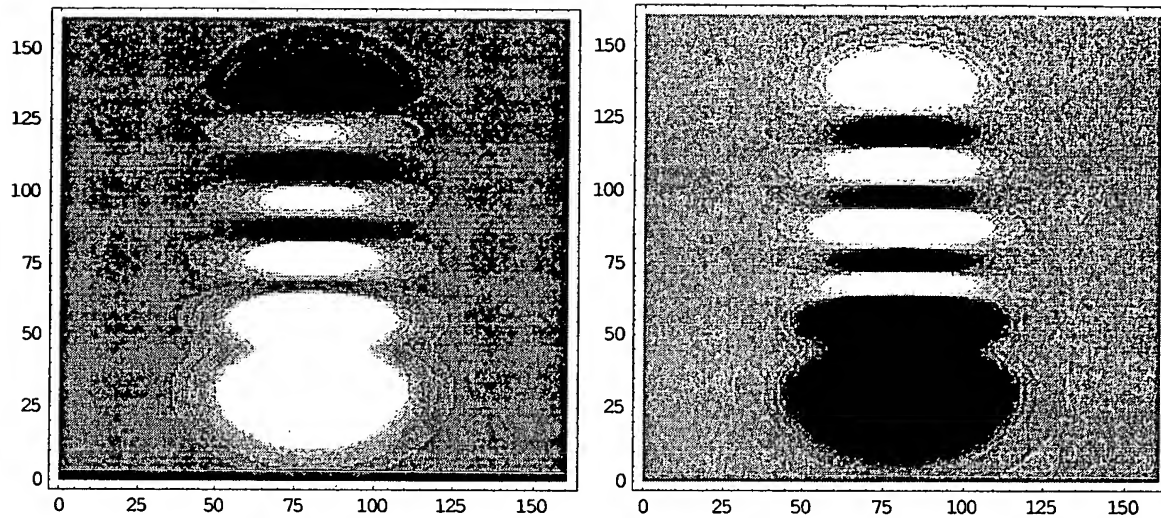
Fig 9A: Outer products of WH0 and 10-OSSO symbol with WH0 Present (left) and Absent (right) from OSSO symbol.
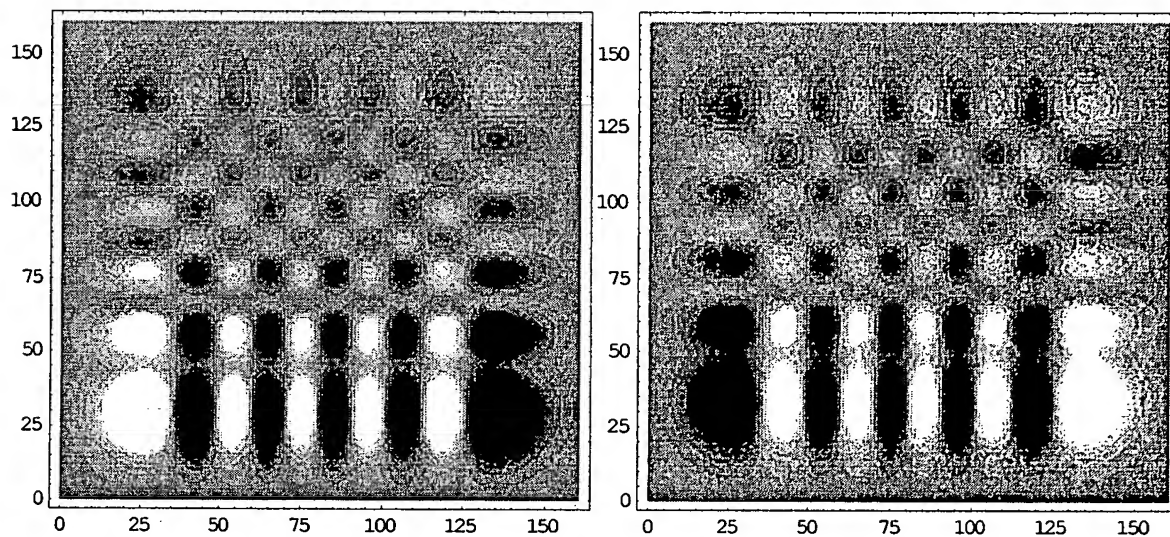

Fig 9B: Outer products of WH9 and 10-OSSO symbol with WH9 Present (left) and Absent (right) from OSSO symbol.
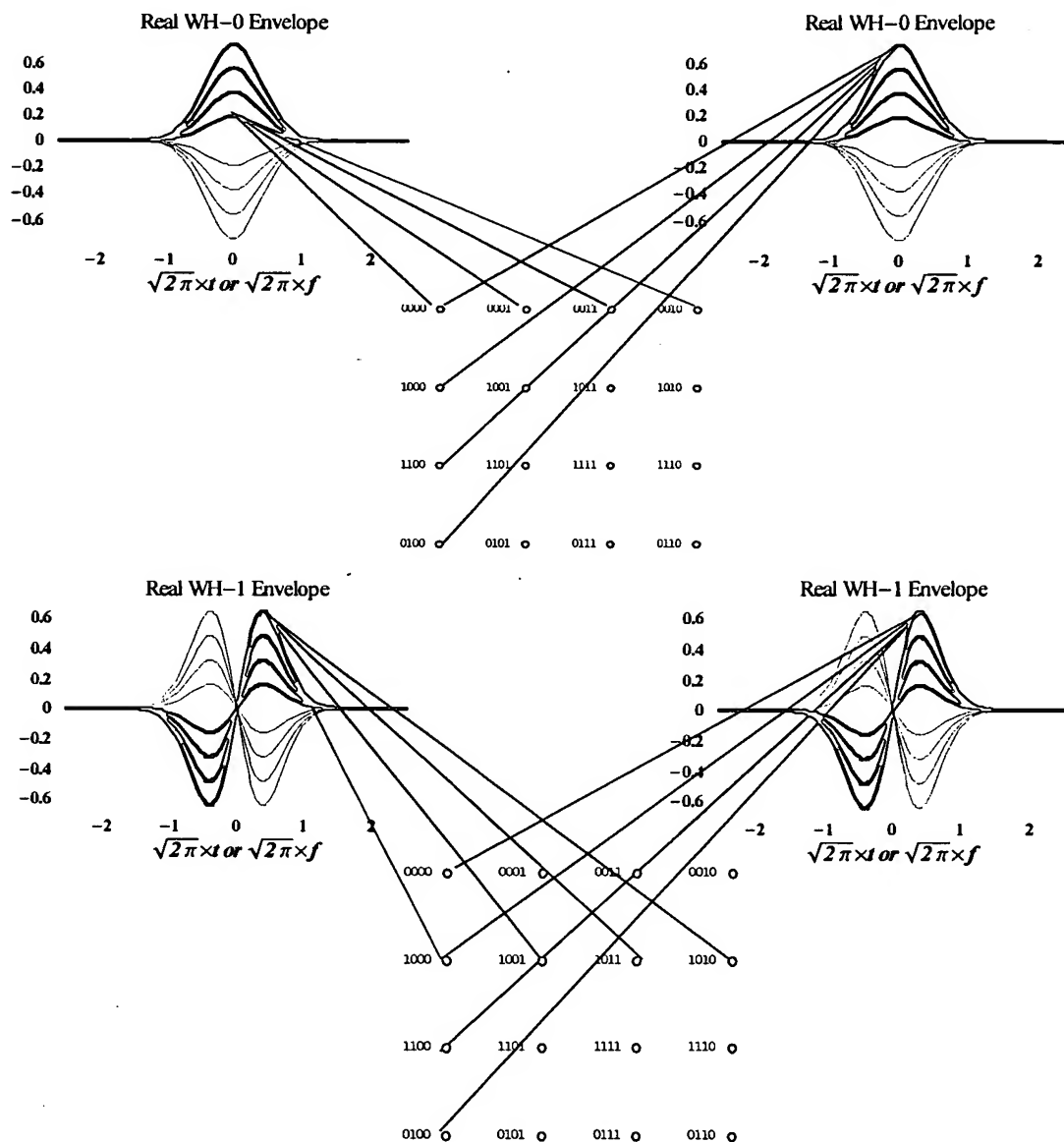
Fig 10A Top: WH0 in I (left) and Q (right) showing amplitude level relationship to a 16-QAM constellation. Bottom: WH1 showing the same relationship but to a separate 16-QAM constellation.
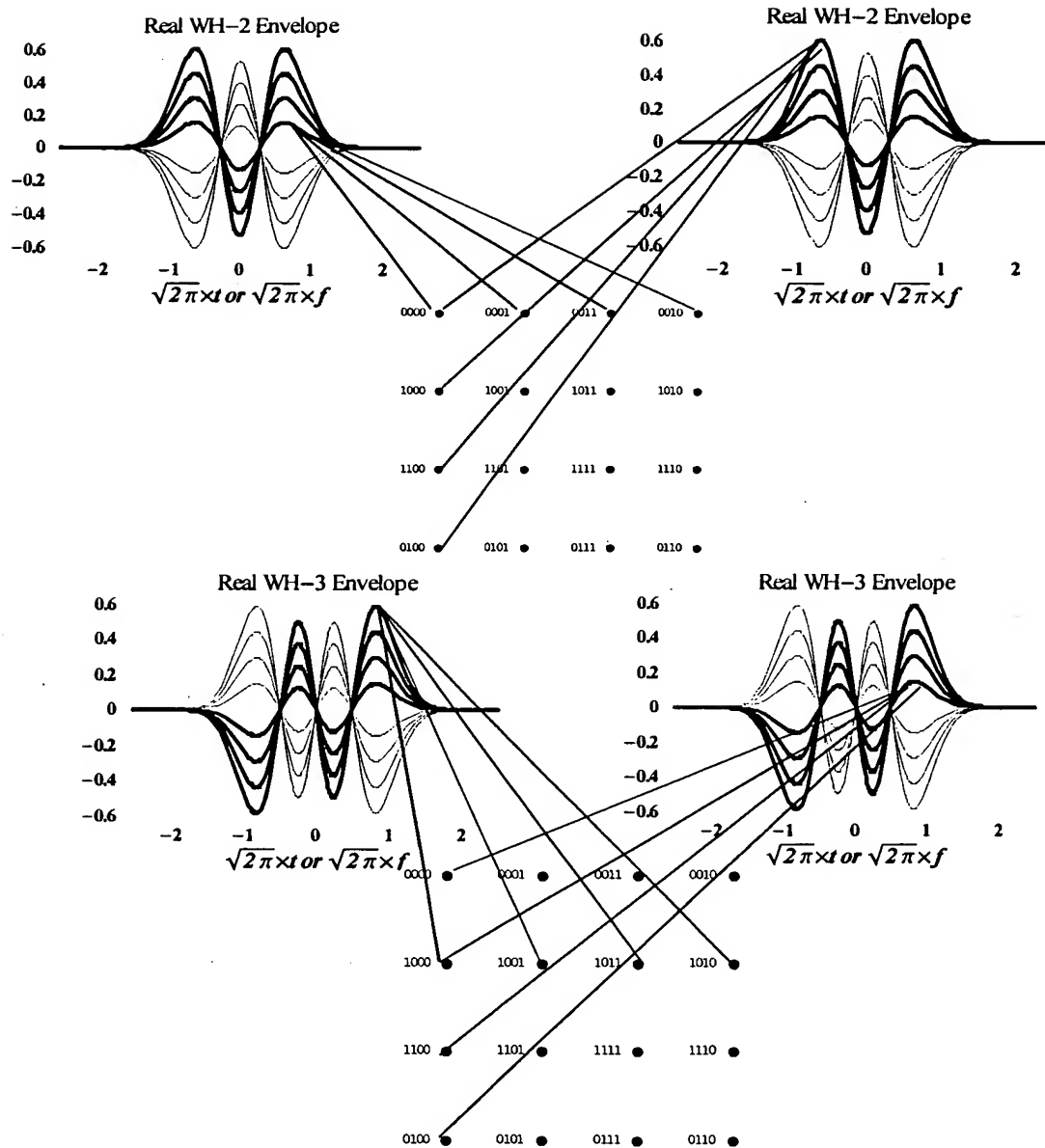
Fig 10B Top: WH2 in I (left) and Q (right) showing amplitude level relationship to a 16-QAM constellation. Bottom: WH3 showing the same relationship but to a separate 16-QAM constellation.
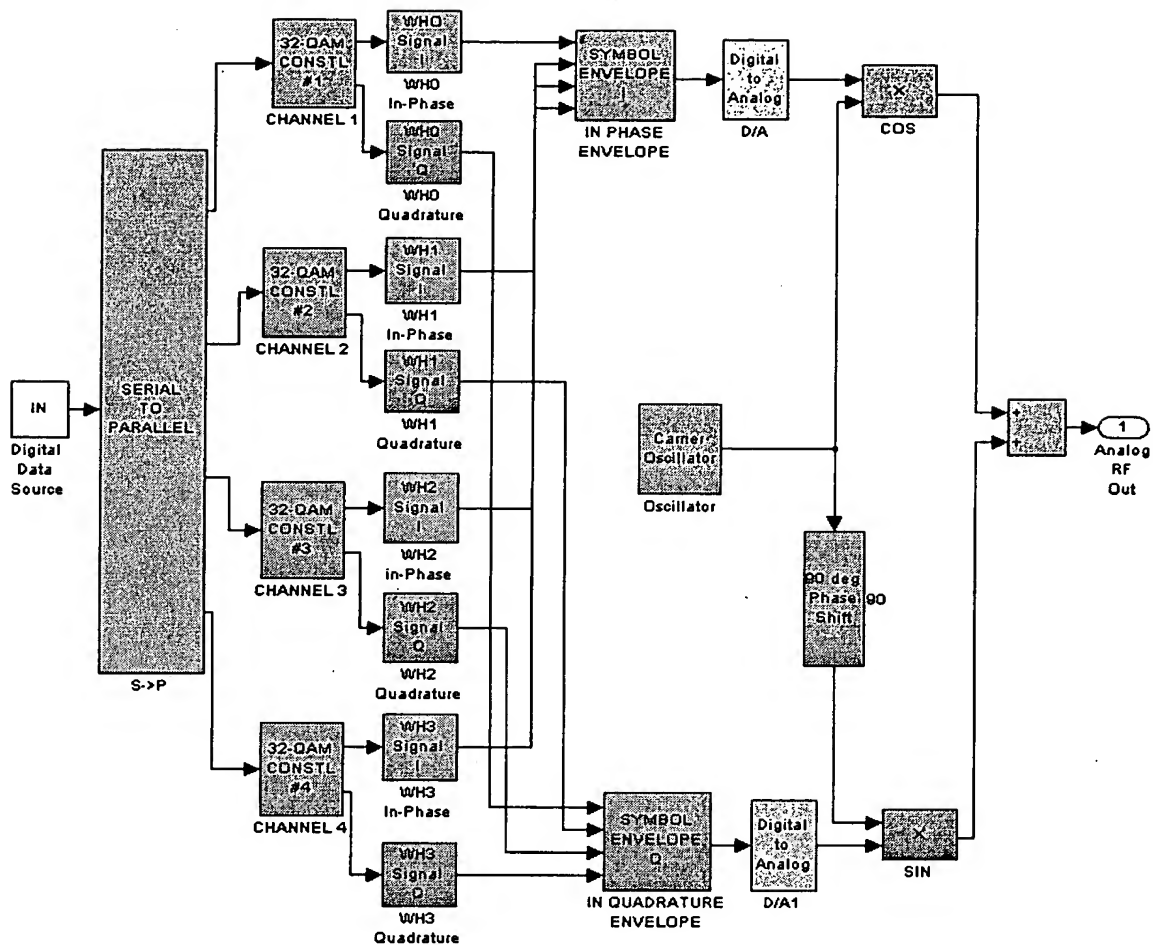
Fig 11A Representative OSSO transmitter: 4-OSSO-32 in which the OSSO symbol is constituted of four WH signals: WH0, WH1, WH2 and WH3, each of which is modulated in I and Q to form four separate 32-QAM channels. This representation is for illustration purposes as many functions can be performed in software and programmable devices such as FPGAs and DSPs.

WH0 Signal I

WH0
In-Phase

WH0 Signal Q

WH0
Quadrature

32-QAM CONSTL #1

CHANNEL #1

WH1 Signal I

WH1
In-Phase

WH1 Signal Q

WH1
Quadrature

32-QAM CONSTL #2

CHANNEL #2

Analog to Digital

ENVELOPE
A/D - I

4 Correlations/ Inner Products In Phase

Correlations
in Phase

WH2 Signal I

WH2
in-Phase

WH2 Signal Q

WH2
Quadrature

32-QAM CONSTL #3

CHANNEL #3

PARALLEL TO SERIAL

1
Digital
Out

IN

Analog
RF
Input

X

Mix
in I and Q

Analog to Digital

ENVELOPE
A/D - Q

4 Correlations/ Inner Products In Quadrature

Correlations
in Quadrature

WH3 Signal I

WH3
In-Phase

WH3 Signal Q

WH3
Quadrature

32-QAM CONSTL #4
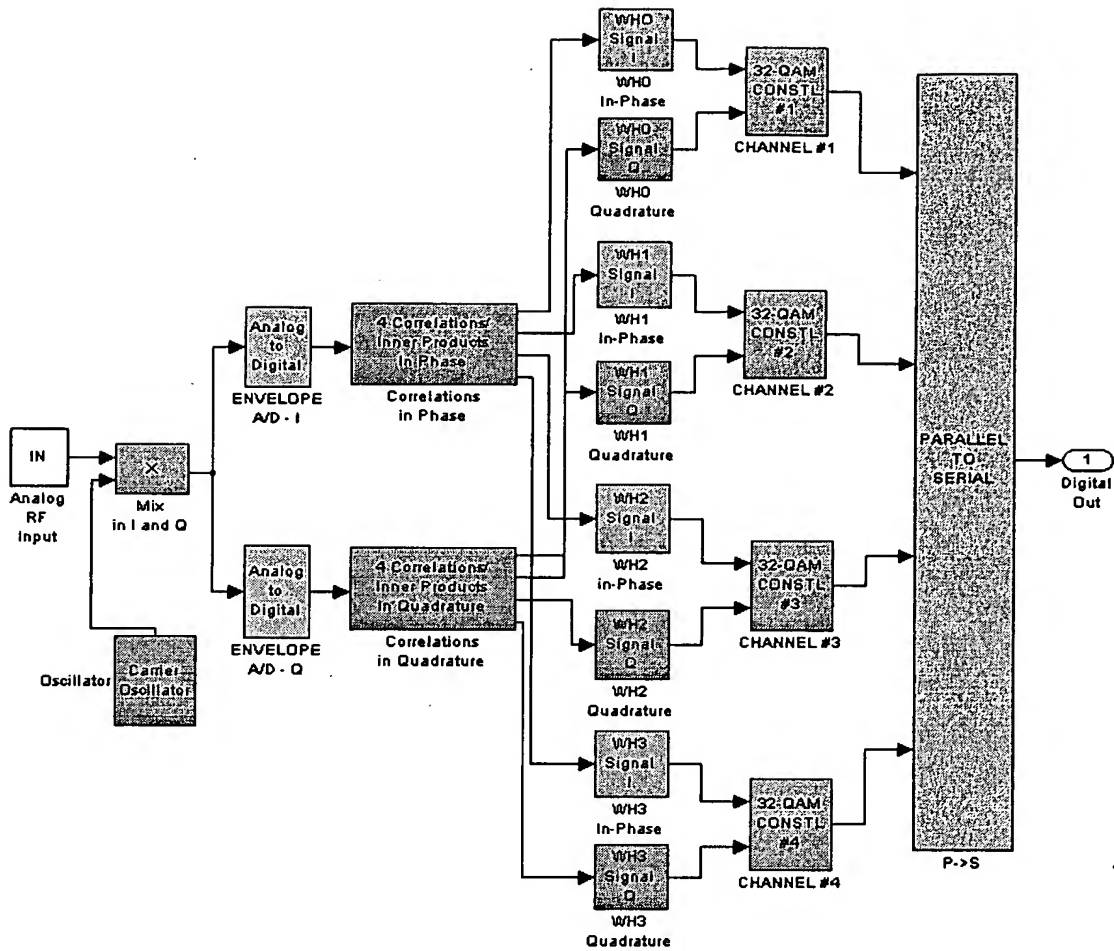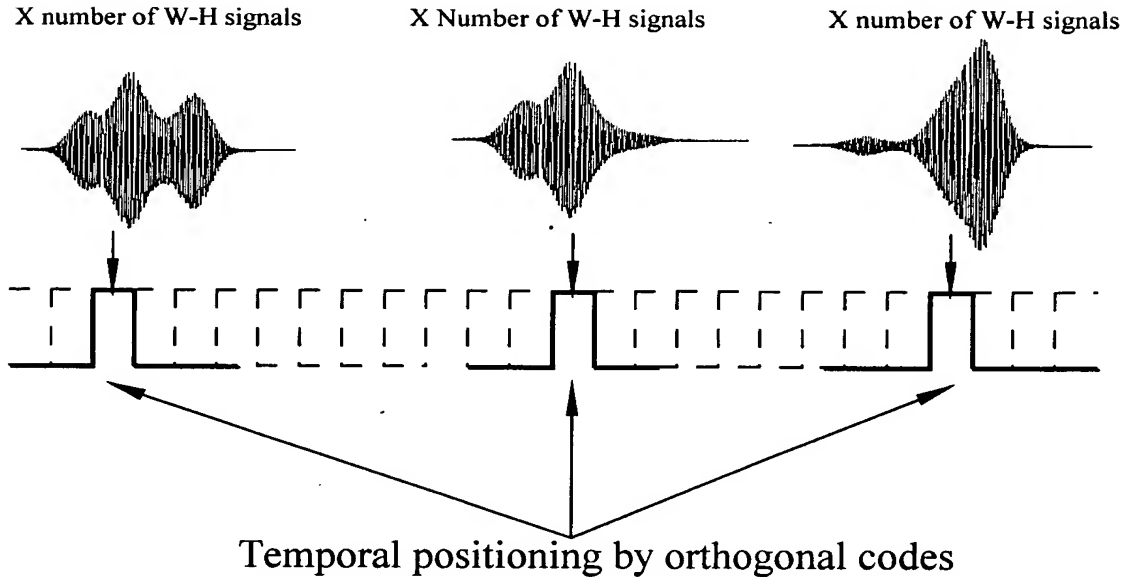
CHANNEL #4

P->S

Oscillator

Carrier Osoillator

Fig 11B Representative OSSO receiver: 4-OSSO-32 in which the OSSO symbol is constituted of four WH signals: WH0, WH1, WH2 and WH3, each of which has been modulated in I and Q to form four separate 32-QAM channels. This representation is for illustration purposes as many functions can be performed in software and programmable devices such as FPGAs and DSPs.

ANALOG: Orthogonal Signal Spectral Overlay (OSSO)

Data encoding by AM or QAM constellations

X number of W-H signals X Number of W-H signals X number of W-H signals

Temporal positioning by orthogonal codes

DIGITAL: Orthogonal Code Schemes (OCS)

Both TDMA and CDMA possible

Fig 12 Representation of positioning of transmitted OSSO symbols using either TDMA or CDMA codes.